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Change in the Sensory Properties of Alkali Activated Slag Mortars

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Abstract

Alkali activated slag mortars can be characterized by shorter setting time and different strengths. Conventional cementitious materials are harder to measure by electrical test methods. It is being researched if the dopant atoms in the form of powder improve the mechanical properties. This article describes how the test slag mortars with addition of carbon powder COND 986 by electrical impedance spectroscopy measurement methods and their extensions in the form of using ZNC vector network analyzer with a coaxial probe from Speag. Impedance spectra of samples were obtained in the 40 Hz to 1 MHz. Declines of impedance by adding more carbon were expected and confirmed. Electrical conductivity and permittivity were measured by vector analyzer for the 100 MHz to 3 GHz. The permittivity was varied from 4 to 20, depending on the addition of carbon.

Keywords: non-destructive testing; slag mortars with addition of carbon; electrical impedance spectroscopy;

1. Introduction

Aluminosilicate production of non-clinker binders is one possible suitable utilization of waste substances. Alternative binders based on alkali activated slag were used in concrete production since the second half of the 20th century, especially in Eastern Europe, Scandinavia and China.

Various kinds of slag can be used, e.g. blast or steel furnace slag, slag from casting of non-ferrous metals and other slags with high content of amorphous phase. These slags have latent hydraulic properties, which can be activated with

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a suitable activator. As activators are used mostly silicates, hydroxides and carbonates of a sodium or of potassium (Fernández-Jiménez et al. 1999).

There are good results in the chemical industry with mixing carbon powder into many materials. Carbon provides firming and greater durability of materials. This paper presents the basic electrical properties of laboratory prepared alkali-activated composite materials based on slag with the addition of different amounts of micronized natural graphite (Cabeza et al. 2002, Ficker et al. 2013, Pazdera et al. 2010).

Impedance spectroscopy (IS) is a non-destructive testing (NDT) method ranking in the electrical engineering measuring method group. It outputs data providing information on material electric and dielectric properties. Microscopically inhomogeneous materials are frequently used in the building industry. Unfortunately, the impedance spectroscopy results and their characterization on the basis of this method are not unambiguous (Kusak et al. 2014).

Admixture of carbon powder should give different electric properties by using alternating electric field than obvious cement based paste. At the Department of Physics, Faculty of Civil Engineering, Brno University of Technology, the IS-based measurements have been implemented using following instrumentation: Agilent 33220A generator, Agilent 54645A double-channel oscilloscope, HP 82350 PCI HP-IB Interface card, and a PC. To operate the above mentioned instruments and to process the IS data acquired, a software called IS alpha has been prepared by the first author of this paper (Mentlik 2006, Lunak et al. 2014).

In order to perform impedance analysis was necessary to place the samples between brass electrodes. The samples were tested for the frequency spectra from 40 Hz to 1 MHz. Monitored variables were: loss factor tan δ (f), the real and imaginary component of impedance Z (f).

Second most important measurement was realized by using the Vector network analyzer ZNC, made by Rohde & Schwarz Company. By using coaxial probe of Speag Company and by using Vector network analyzer, we can measure loss factor, dielectric permittivity and conductance, with very high speed, for frequency range 100 MHz ÷ 3 GHz (Kusak et al. 2013, Macdonald 1987).

2. Measured Specimens

Alkali-activated finely ground granulated blast furnace slag was chosen as a binder. Activation was carried out by water-glass solution, Susil MP 2,0. As filler were used both test norm-sand (0÷4 mm) and carbon powder Cond 896. Triton X-100 was used to treat the graphite surface and defoaming agent Lukosan S was added to minimize the gas content. The compositions of each mixture are summarized in Table 1.

Table 1. Recipes of mixtures of specimens.

Components / COND	Ref	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
slag [g]	450	450	450	450	450	450	450	450	450	450	450
Susil [g]	90	90	90	90	90	90	90	90	90	90	90
sand [g]	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350	1350
COND 8 96 [g]	0	4.5	9	13.5	18	22.5	27	31.5	36	40.5	45
0.5 % Triton X 100 [ml]	0	30	30	30	30	60	60	90	90	120	120
1 % Lukosan S [ml]	0	5	5	5	5	10	10	15	15	20	20
water [ml]	185	150	155	160	165	135	140	110	115	85	90

Mixing method: Water-glass Susil and Triton treated graphite powder were put together with a part of water (about 100 ml) and stirred in a mixer for 1 min. Then the slag, sand, the rest of the water and Lukosan S was added and stirred for another 1 min. After demoulding, the samples were stored in water for 28 days and then 7 days in standard laboratory conditions for the moisture stabilization.

The specimens were produced with dimensions of 40×40×160 mm. The individual results are compared with a reference sample.

3. Experimental results

Interesting results were found for all measured samples in the spectrum of loss factor. The spectra show polar dielectric properties at its shape. The sample which does not contain carbon admixture has only one polarization maximum for frequency 600 Hz and tan $\delta = 9$. The sample contained only alkali-activated slag, sand, water glass and water.

And as carbon powder was added, polarization losses fell below 5. Another addition of carbon powder significantly decreased the polarization losses in the region of 500 Hz again, but the curve in the $10^4 \div 10^6$ Hz increased. The presence of carbon powder, first decreased electrical resistance of the material, but carbon also added particles for creating dipole elements to the sample. Particles are well-polarizable across the entire frequency spectrum.

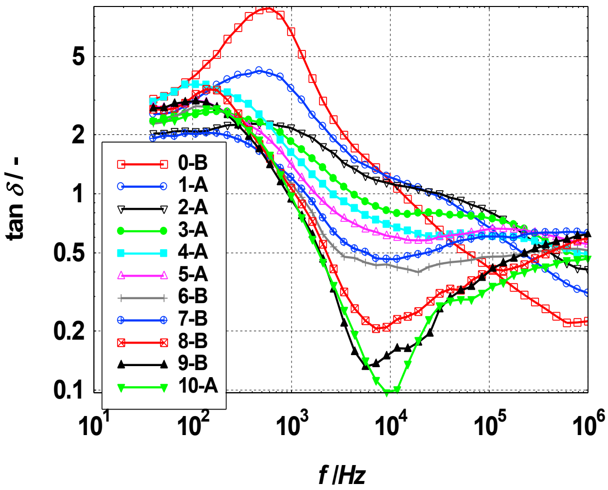

Fig. 1 Dielectric loss factor versus frequency dependence.

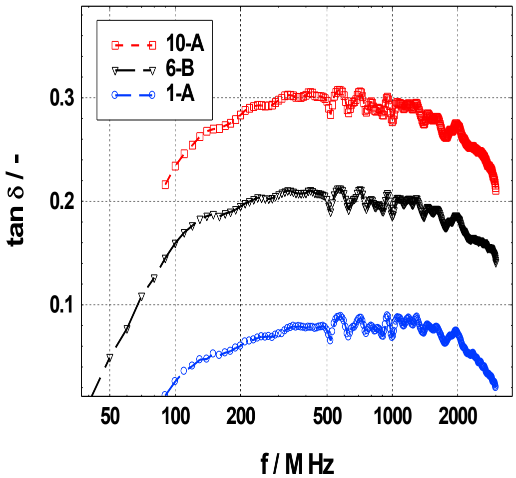

Fig. 2 Dielectric loss factor versus frequency dependence. Measured by Vector network analyzer.

For 4 % COND in the mixture there was observed again an increase of polarization loss in the low frequencies, the maximum is shifted to 100 Hz, while in the 600 Hz there is an inflection point at which the value of tan delta is lower than previously presented at an interval 600 Hz to 200 kHz. The values of dissipation factor for range 40 Hz to 600 Hz are in the range 1.5 to 4 and reach polarization maxima here.

By using a logarithmic scale, Fig. 1, for tan δ we get much more transparent view of areas of low values of tan delta. These peaks, however, "jump" with addition of water and carbon at 5 % of the mixture, and 9 % COND of the mixture. If maxima grow for low frequencies and by adding carbon powder too, this indicates the influence of the mixing water to the polarization losses in selected low frequencies.

From 600 Hz to 200 kHz, the values of tan delta decreased with increasing content of carbon powder to a value of tan $\delta = 0.1$. Simultaneously water content was reduced, content of Triton increased. The amount of particles capable of polarization decreased for the frequency of 1 kHz to 100 kHz. For high frequency bands, the levels of values of dissipation factor are comparable, reaching the values around 0.5.

Low values of dissipation factor were measured using the vector analyzer. They ranged from 0.01 to 0.4, again depending on the concentration of carbon powder (Fig. 2). The curves differ not only by the level but also by the shape, but insignificantly. Measuring by vector analyzer by Speag probe are designed for gaseous and liquid environments, and measurements on solids depend greatly on the surface flatness of the material, on the closest possible of attach to the surface of the sample.

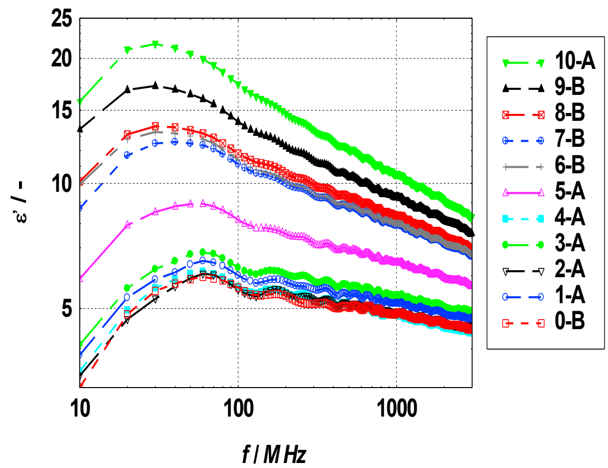

Fig. 3 Spectra of real part of permittivity, measured by Vector network analyzer.

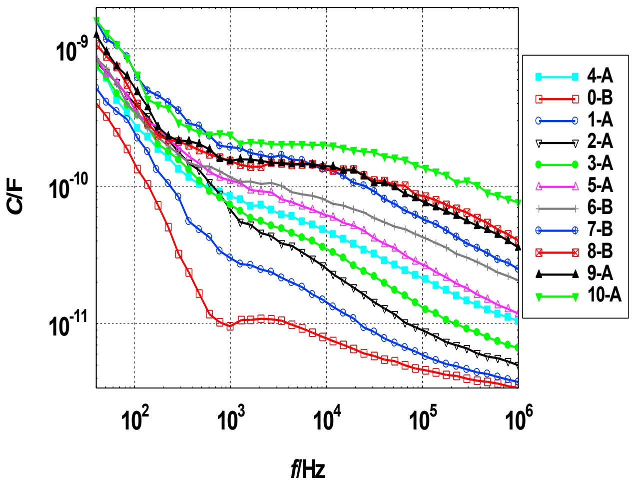

Fig. 4 Spectra of electric capacity for used samples.

The measurement by using vector analyzer showed relatively low values of the real component of permittivity of material (Fig. 3) for the frequency range 100 MHz to 3 GHz. Acquiring values of 5 to 22 about the first three to five values for the lowest frequency was measured significantly lower than the maximum value. This discrepancy is attributed to significant error determination of the first values for lowest frequencies; it is advisable not to take these values as relevant. The threshold of the measurability by vector analyzer was intended to determine. The presented measurement is perhaps the first diagnosis of the building materials in the world, using this top equipment.

Permittivity in the area of higher frequency for the incorporation of carbon powder is increasing rapidly for concentration of 5 % and higher. With increasing of frequency the values of permittivity decrease.

Electric capacity for low used frequency range 40 Hz up to 1 MHz show in Fig. 4 similar trend. Lowest values of capacity were measured for material with no contribution of carbon powder. For whole frequency spectra we can see bigger values of electric capacity near 0.5 nF, then the capacity rapidly decreases to 10^{-11} F for 1 kHz. Then the capacity decreases slowly. Carbon powder with bigger concentration for next specimens created more dipole elements, which created more charge by application of outside electric alternating field. The decrease of electric capacity with higher frequencies is smaller with high content of carbon powder. But for lowest frequencies is not the difference so great.

Imaginary part of impedance versus real parts of impedance (Fig. 5) dependences for all samples have decreasing trend for increasing of weight of carbon powder at mortars. Right edge of spectra belongs to low frequency of electric field. Spectra were obtained using old method (generator, oscilloscope, pc), so the lowest frequency is 40 Hz, the biggest frequency is 1 MHz. Impedance parts dependence create semi arcs, little depressed below x axis. For samples 0, 1, 2 there is decreasing of x and y values. For specimens 3, 4, 5, 6 we can observe bigger values of top of the arc than for samples with smaller numbers. Specimens 7, 8, 9, 10 have smaller weight of water and bigger weight of carbon powder. Specimens 8, 9 have more regular semi arc than previous specimens have.

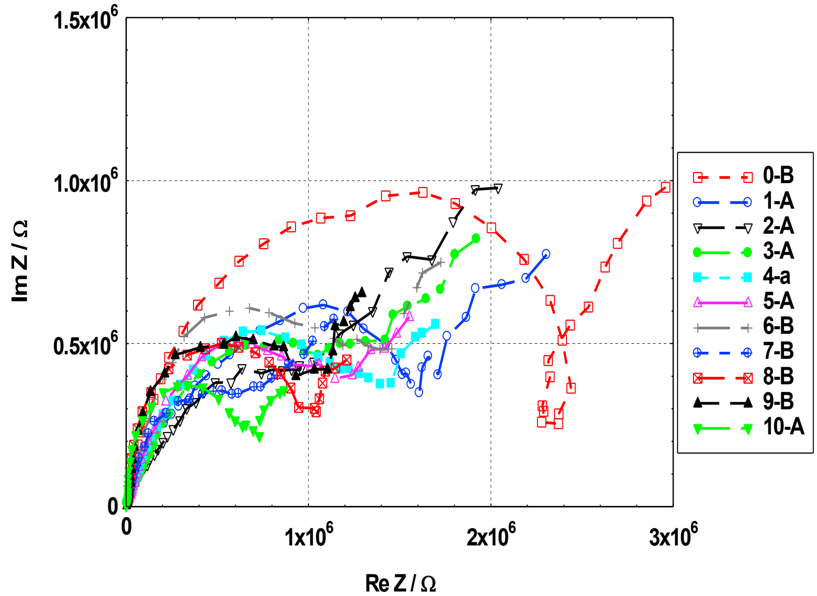

Fig. 5 Imaginary parts and real parts of impedance for all samples.

4. Summary

The addition of carbon powder into alkali-activated slag mortars has changed electrical properties of the samples. Carbon particles cause higher conductivity of material, also increases the electrical capacity of the sample. Observing the effect of admixture of carbon on the hardness and abrasion resistance of the samples was the subject of this article. Carbon additives help to improve the electromagnetic shielding of construction by using waste products from the production of carbon products.

The measurability of samples using the vector analyzer was confirmed. This method does not require specially treated samples, only the smoothness of the contact surface area is necessary.

Acknowledgements

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